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We will show that if you design the cable so that the voltage drop is limited to 4% of 230V (i.e. about 9.2V drop) then the “single-phase” option (which has to run out and back – a total of 240m) requires roughly twice as much cross-section per core as a “three-phase” (4-wire) supply where the phase conductors run only 120m. (In a balanced 3-phase system the neutral need not be sized for voltage drop and – if allowed – may be reduced in size for normal operation.)

In what follows the resistivity of copper is taken as

$$\rho = 0.02 \times 10^{-6} \Omega\text{m} = 2.0 \times 10^{-8} \Omega\text{m}.$$

1. Single-Phase Option

A single-phase circuit from substation to building runs 120m out and 120m back. (The “circuit length” is therefore 240m.) For a purely resistive conductor the voltage drop is

$$\Delta V = I R \quad \text{with} \quad R = \frac{\rho L}{A}.$$

Since current flows in both conductors the drop is

$$\Delta V = I \frac{2\rho L}{A}.$$

We require that

$$I \frac{2\rho L}{A} \leq 0.04 \times 230 = 9.2 \text{ V}.$$

Inserting the numbers with $I = 180 \text{ A}$ and $L = 120 \text{ m}$ (remembering that the “2” already accounts for the return path):

$$A \geq \frac{I(2\rho L)}{9.2} = \frac{180 \times (2 \times 2.0 \times 10^{-8} \times 120)}{9.2}.$$

Let’s compute the numerator step-by-step:

- $2\rho L = 2 \times 2.0 \times 10^{-8} \times 120 = 4.0 \times 10^{-8} \times 120 = 4.8 \times 10^{-6} \Omega\text{m}.$
- Multiplying by 180 A gives:

$$180 \times 4.8 \times 10^{-6} = 8.64 \times 10^{-4}.$$

Thus

$$A \geq \frac{8.64 \times 10^{-4}}{9.2} \approx 9.39 \times 10^{-5} \text{ m}^2.$$

Converting to square millimetres ($1\text{m}^2 = 1 \times 10^6 \text{mm}^2$):

$$A \approx 93.9 \text{ mm}^2.$$

That is, each conductor must be about 94mm². (Cable sizes would normally be rounded up to the next standard size.) Since the cable is 2-core the total copper cross-section is

$$A_{\text{total(single)}} = 2 \times 94 \approx 188 \text{ mm}^2.$$

2. Three-Phase (4-Wire) Option

When a three-phase 400/230V supply is used to feed balanced 230V loads (180A per phase), the voltage drop on the phase conductor is calculated only over the 120m run from the substation to the building. (Under balanced conditions the neutral carries little or no current so its voltage drop is negligible.) Thus we require

$$\Delta V = I \frac{\rho L}{A_{\text{phase}}} \leq 9.2 \text{ V},$$

or

$$A_{\text{phase}} \geq \frac{I \rho L}{9.2}.$$

Now with $I = 180 \text{ A}$ and $L = 120 \text{ m}$:

$$A_{\text{phase}} \geq \frac{180 \times (2.0 \times 10^{-8} \times 120)}{9.2}.$$

Let's calculate:

- $\rho L = 2.0 \times 10^{-8} \times 120 = 2.4 \times 10^{-6} \Omega\text{m}.$
- Multiplying by 180 A gives:

$$180 \times 2.4 \times 10^{-6} = 4.32 \times 10^{-4}.$$

- Dividing by 9.2 V:

$$A_{\text{phase}} \geq \frac{4.32 \times 10^{-4}}{9.2} \approx 4.70 \times 10^{-5} \text{ m}^2,$$

or

$$A_{\text{phase}} \approx 47 \text{ mm}^2.$$

Thus each phase conductor must be about 47mm².

Now regarding the neutral: because the loads are balanced the neutral current is (ideally) zero so its conductor need not be sized for voltage drop. However, protection requirements (and fault conditions – note the 10kA earth-fault current rating) may require the neutral to have a minimum cross-section. In many design practices (for example under BS 7671) it is acceptable to use a

neutral that is smaller – often around 50% of the phase size – when the load is balanced. Thus one may take

$$A_{\text{neutral}} \approx \frac{1}{2} A_{\text{phase}} \approx \frac{1}{2} \times 47 \approx 23.5 \text{ mm}^2,$$

which would normally be rounded to a standard size of about 25mm².

Since the 4-core cable must supply three phases plus neutral, the total copper area (by summing the areas in each core) is

$$A_{\text{total(3-phase)}} = 3 \times 47 + 25 = 141 + 25 = 166 \text{ mm}^2.$$

3. Percentage Saving

Compare the total copper used in each option:

- **Single-phase total:** 188mm²
- **Three-phase total:** 166mm²

The saving is

$$\text{Saving} = \frac{188 - 166}{188} \times 100\% \approx \frac{22}{188} \times 100\% \approx 11.7\%,$$

i.e. roughly a 12% saving in copper conductor area when using a three-phase 4-wire supply instead of a separate single-phase supply.

Summary of Answers

- **Single-phase option:**
Use a 2-core cable with each conductor sized at about **94mm²** (total copper area $\approx 188\text{mm}^2$).
- **Three-phase option:**
Use a 4-core cable with each phase conductor sized at about **47mm²** and (by good practice) a neutral conductor of about **25mm²** (total copper area $\approx 166\text{mm}^2$).
- **Copper saving:**
The three-phase system uses roughly **12% less** copper than the single-phase option.

These results are based on limiting the voltage drop to 4% of 230V and assuming that the balanced three-phase system permits the neutral to be taken at about half the size of the phase conductors for normal operating conditions.
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